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SHORT COMMUNICATION

Phototactic Behavior: Attractive Effects of *Spodoptera litura* (Lepidoptera: Noctuidae), Tobacco Cutworm, to High-power Light-emitting Diodes

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Abstract Phototactic responses of *Spodoptera litura* adults to high-power light-emitting diodes (HPLEDs) were investigated at four different wavelengths, various light intensities, and light-exposure times under laboratory conditions. All light sources were significantly attractive to *S. litura* adults at 40 lx light intensity and 60 min light-exposure time; thus they were established as the optimal conditions. When the attraction rate of *S. litura* adults was surveyed at the optimal conditions, the green HPLED (520±5 nm) exhibited the highest potential attraction rate (64.3%), followed by the blue HPLED (470±10 nm, 47.7%), the yellow HPLED (590±5 nm, 33.3%), and the red HPLED (625±10 nm). Compared to fluorescent light, which was used as a positive control (380–800 nm, 50.0%), the green HPLED was approximately 1.3 times more effective at attracting *S. litura* adults. In conclusion, use of the green HPLED (520±5 nm) was the most suitable for attraction of *S. litura* adults under optimal conditions.

Keywords attraction rate · high-power light-emitting diode · phototactic response · *Spodoptera litura* · tobacco cutworm

Insect pests, which disrupt the growth of agricultural crops and cause economic loss, have been reported to damage between 10 and 30% of major crops (Ferry et al., 2004). *Spodoptera litura*, known as the tobacco cutworm, is an economically important polyphagous insect that possesses a high reproductive rate and the ability to migrate over large distances in the adult stage (Hummelbrunner and Isman, 2001). Due to these characteristics, *S. litura* has caused severe damage throughout its geographical range to many agricultural crops and vegetables (Armes et al., 1997). Over the past half-century, the management of *S. litura* adults has principally depended on the use of synthetic insecticides. However, the use of synthetic insecticides in insect pest-control programs around the world has resulted in adverse effects to the environment and non-target organisms as well as in the resurgence of the pests (Wei et al., 2004). Potential problems associated with repeated long-term use of toxic insecticide include resistance and a negative impact on natural enemies. Although the aim of insecticide application is to kill all target pests, resistance of target species to particular compounds has gradually developed. Therefore, a new strategy for the management of insect pests involving safe and effective control systems, such as light traps, natural insecticides, and pheromone traps, is needed (Ahn et al., 1998; Park et al., 2000).

In humans, color can be described in terms of brightness, hue, and saturation (Long et al., 2006). However, the responses of insect pests to light of varying wavelengths and intensities are not well understood. Insect pests are attracted to light of different wavelengths under the influence of internal and external biotic and abiotic factors (Briscoe and Chittka, 2001). Light traps with fluorescent lamps are commonly used to monitor the presence of insect pests, to compare their relative abundances, and to conduct research. In general, insects perceive and respond to light in the 350–700 nm (visible light) range, and their relative behavior can vary considerably over this range. Advances in high-power light-emitting diodes (HPLEDs) have produced small-sized devices that operate at selective wavelengths with high luminous efficiency and low thermal output (Bishop et al., 2004). Therefore, the present study was conducted to determine the response of a range of *S. litura* adults to different wavelengths in the visible spectrum with the use of HPLEDs.

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Adults of *S. litura* were obtained from the National Academy of Agricultural Science, Rural Development Administration (Suwon, Korea) and were reared in a growth cage (35 cm × 35 cm × 35 cm) at room temperature, 65% relative humidity, and a 16 h light/ 8 h dark photoperiod cycle. The artificial diet of *S. litura* consisted of kidney bean powder (31.4%), wheat germ (31.4%), dried yeast (16.7%), agar powder (7.5%), and other ingredients (13%).

The HPLEDs were purchased from the Ciel Light Corporation (Korea) or the Photron Corporation (Korea). The colors, part numbers, wavelengths, luminous flux (lm), and maximum power consumption (W) were as follows: blue HPLED (CL-1W-UBB, 470±10 nm, 15.0±3.1 lm, 1 W), green HPLED (CL-1W-UPGB, 520±5 nm, 45.0±3.5 lm, 1 W), yellow HPLED (PP592-8L61-AOBI, 590±5 nm, 40.0±10.0 lm, 1 W), and red HPLED (CL-1W-URB, 625±10 nm, 35.0±1.2 lm, 1 W). HPLED circuit boards (7 × 14 cm) consisted of 40 HPLEDs of each color. A large circuit board (30 × 15 cm) was designed to be wall-mounted to the light side of the test chamber together with three HPLED circuit boards to allow quick and easy replacement. The light intensity of the large circuit board could be adjusted using an electric power controller and power supply (S-100-36: MEAN WELL Technology Co., Ltd., Taiwan). A fluorescent light bulb (T5-508W, Hangzhou Lijing-Lighting Co., Ltd., China) served as a positive control and was compared to the tested HPLEDs of various wavelengths.

The test chamber of Oh and Lee (2010) was used with slight modification and consisted of one acrylic body (50 cm × 150 cm × 30 cm) and two acrylic walls that were fitted at both ends of test chamber, located inside. The power supply was a standard 220 V alternating electricity source. Insect entrance holes were created at the centers of the chambers to efficiently disperse the *S. litura* adults; nylon netting inside the chamber prevented the insects from escaping. The inner chamber consisted of two movable plates and an opaque partition for controlling the light exposure and terminating the insect responses. The test chamber was maintained at 27±0.5°C and 60±5% relative humidity in darkness using two holes (10 × 10 cm, covered with wire netting) in the rear wall.

The responses of *S. litura* adults to the HPLED light sources were observed under conditions in which the specific wavelength, illuminance intensity, and light-exposure time in the test chamber were varied. After 30 *S. litura* adults were collected by a converted vacuum cleaner, they were released into the test chamber through the insect entrance hole. Illuminance intensity (lx) of the HPLEDs was measured from the middle position (70 cm) of the test chamber using an illumination meter (LM-332, AS ONE Co., Ltd., Japan). The attractiveness of the four HPLEDs to *S. litura* adults was determined by counting the number of existing moths in the "light" and "dark" sides of the test chamber. The attraction of insects to the HPLEDs at five illuminance intensities between 20 and 100 lx, inclusive, at 20 lx intervals, was measured. Next, the attraction of insects at different light-exposure times (20, 40, 60, 80, and 100 min) was measured in a test chamber at the optimal intensity. Finally, the attraction of *S. litura* adults to each of the four HPLEDs was measured under optimal conditions of illuminance and exposure time. All experiments were repeated three times. One-way analyses of variance (ANOVA) using SPSS statistical software (version 18.0, SPSS Inc., USA) were used to compare the numbers of *S. litura* adults in the attraction tests. Duncan's multiple-range test was performed to compare differences among the mean values at $p<0.05$. Data were expressed as means ± standard error of the mean (SEM).

The attractiveness of specific wavelengths, illuminance intensities, and exposure times were compared to that of fluorescent light, which served as a positive control. The attraction rates of the four HPLEDs under various intensities are shown in Table 1. At 40 lx,

Table 1 Attraction rates of *Spodoptera litura* adults to four HPLEDs under various illuminance intensities (lx)[1)]

Color	Wavelength (nm)	Attraction rates (%)[2)]				
		20 lx	40 lx	60 lx	80 lx	100 lx
Blue	470±10 nm	34	52	44	39	35
Green	520±5 nm	42	64	51	46	32
Yellow	590±5 nm	29	41	36	24	21
Red	625±10 nm	25	33	28	22	19

[1)]Each value is the average of three determinations after 30 min exposure, with 30 adult insects per replication.
[2)]Attraction rate (%) is the average percentage of the 30 *S. litura* adults attracted to various illuminance intensities.

Table 2 Attraction rates of *S. litura* adults to four HPLEDs under various light-exposure times (min)[1)]

Color	Wavelength (nm)	Attraction rate (%)[2)]				
		20 min	40 min	60 min	80 min	100 min
Blue	470±10 nm	38	47	51	48	49
Green	520±5 nm	44	50	63	63	63
Yellow	590±5 nm	27	30	41	34	33
Red	625±10 nm	21	25	33	27	26

[1)]Each value is the average of three determinations at each light-exposure time, at 40 lx, using 30 adult insects per replication.
[2)]Attraction rate (%) is the average percentage of 30 *S. litura* adults attracted by the end of each light-exposure time.

Table 3 Attraction rates of *S. litura* adults to four HPLEDs and to fluorescent light under optimal conditions (40 lx illuminance and 60 min exposure)[1)]

Color	Wavelength (nm)	Insect population (mean ± SE)			Attraction rate (%)[2)]
		Light side	No choice	Dark side	
Blue	470±10	14.3±0.9b	8.0±0.6b	7.7±0.3b	47.7
Green	520±5	19.3±0.7c	6.3±0.3c	4.3±0.3c	64.3
Yellow	590±5	10.0±1.2ab	8.3±0.9ab	11.6±0.9ab	33.3
Red	625±10	9.0±0.6a	10.3±03a	10.6±0.9ab	30.3
Fluorescent	380–800	15.0±1.2bc	8.3±1.5ab	7.3±0.3a	50.0

[1)]Each value is the average of three determinations using the optimal light-exposure time at 40 lx, with 30 adult insects per replication.
[2)]Attraction rate (%) is the average percentage of the 30 *S. litura* adults attracted toward the light side of the test chamber.

all light sources were highly attractive to *S. litura* adults; the attraction rate declined with increasing intensity. Among the HPLEDs, the green HPLED had the highest attraction rate (64%) at 40 lx, followed by the blue HPLED (52%), the yellow HPLED (41%), and the red (33%). Next, the attraction of *S. litura* adults to the four HPLEDs was determined under varying exposure times. The optimal light-exposure time for all light sources was 60 min; there were no significant differences in the percentages of attracted moths as the duration of exposure increased above 60 min (Table 2). The green HPLED showed the highest attraction rate (63%) at the optimal exposure time, followed by the blue HPLED (51%), the yellow HPLED (41%), and the red (33%). The attraction rates of *S. litura* adults under varying exposure times were similar to their rates at the tested intensities.

Finally, these experiments were repeated using the four HPLEDs under optimal conditions (illuminance intensity of 40 lx and 60 min exposure time), and the results were compared to the attraction rates of fluorescent light under the same conditions (Table 3). Under these optimal conditions, the attraction rate of the green HPLED was approximately 1.3 times higher (64.3%) than that of fluorescent light (50.0%) followed by the blue HPLED (47.7%), the yellow HPLED (33.3%), and the red HPLED (30.3%). Significant differences in the attractive effects of green HPLED were observed. These results indicate that the attraction rate depends on the specific wavelength, illuminance intensity, and light-exposure time. Under optimal conditions, the green HPLED was the most suitable for attracting *S. litura* adults.

Recently, traditional insecticides, which can cause environmental damage, resistance, and residual toxicity, have begun to be replaced with eco-friendly insect pest control systems. HPLED light traps may be useful tools for attracting or repelling many insect pests (Castrejon and Rojas, 2010). Previous studies have shown that light color, illuminance intensity, and light-exposure time are important factors in the attraction of insect pests, but few studies to date have examined the management of insect pests using HPLEDs (Castrejon and Rojas, 2010). Hoel et al. (2007) reported that mosquito light traps fitted with LEDs at different wavelengths may serve as substitutes for incandescent light lamps. Oh et al. (2011) evaluated the response of *S. exigua* adults to four HPLEDs (blue, green, yellow, and red) and found that, as in the present study, a green HPLED (520±5 nm,) at 40 lx and with an exposure time of 60 min was the most attractive. Taken together, the work of Oh et al. and the present study suggest that light traps equipped with green HPLEDs may be a new pest control strategy. Further research is needed to compare the efficiencies of HPLEDs on a wide range of agricultural insect pests, develop combined multiplex HPLEDs that enhance the attraction of *S. litura* adults, and aid in the development of sustainable agricultural systems that use these devices.

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